

Active Voltage Contrast and Seebeck Effect Imaging as Complementary Techniques for Localization of Resistive Interconnections

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Introduction

Defective interconnections are a common issue in semiconductor production and pose a problem with every new technology generation. The usual way of monitoring process stability and defect density is to utilize test structures in the kerf or on special test chips. The diagnosis of the failure mode first requires the localization of the failing via before the visualization is performed. The exact localization is challenging when the test array consists of several thousand interconnections and is even more difficult when we have to deal with contacts on active area due to leakage currents into the substrate. Interconnections which are not open but just show a higher resistance are also hard to find. In these cases well known techniques like passive voltage contrast are not successful. In our failure analysis flow we have introduced a combination of Active Voltage Contrast (AVC) and Seebeck Effect Imaging (SEI) to address this kind of failures.

This paper shows that AVC and SEI are complementary methods to localize defective interconnections in cases where passive Voltage Contrast or other laser scanning techniques fail.

Active Voltage Contrast

Voltage contrast is widely utilized as a localization method for opens (or shorts) on circuits and test structures. However, if used in a passive way without applying voltage to the circuit, this approach implies that a clear distinction between a floating and a grounded part of the circuit is possible. When this is prevented by design or defect type, passive voltage contrast reaches its limits. For example, contact chains on p- or n-doped substrate are very hard to analyze since the whole structure is not floating. Small leakage currents are running from each contact into the substrate layer which makes passive approaches impossible. The contact chain cannot be charged by the electron beam and remains bright in the SEM contrast even when the chain is interrupted by an open contact. There are two ways to overcome this problem: One is the recently developed Active Voltage Contrast [1]. We use a probing system (Kammrath & Weiss) which is integrated into a FEI dual beam tool. A bias is applied to one side of the chain, and the other side is put on ground. With the applied voltage the chain is charged on a level that compensates the substrate

leakages. This leads to a visible contrast in the SEM image which can not be seen with passive techniques. The point between the dark and bright areas marks the open interconnection and allows direct x-sectioning and imaging in the dual beam tool.

The same method is performed when interconnections on higher metallization are to be analyzed. If a low ohmic defect is suspected a direct active approach is preferred. Even if a successful localization by passive voltage contrast is not excluded prior to analysis and would be the easier way, it is often skipped as the DUT is irreversibly modified: To enable PVC one side of the structure is usually grounded by milling a hole into the pad to connect it with substrate thus making subsequent active biasing difficult.

Seebeck Effect Imaging

Seebeck Effect Imaging [2] has advantages over Active Voltage Contrast when the failing structure is hidden under several metal layers. Mechanical delayering to enable voltage contrast can be difficult if the test structure is very large because the required lateral uniformity is not always reached. The thermoelectric effect of local heating by an infrared laser beam on the junctions is monitored at the pads that connect the chain. The images presented below were taken with a Hamamatsu Phemos1000 using an IR-laser.

Although the lateral resolution of SEI images is limited by the laser wavelength it delivers additional information compared to AVC. Not only open vias are localized, but small differences in resistance between the interconnections can be made visible yielding a two dimensional resistance mapping of the test structure.

Via Localization Challenges

The test structures used for this paper are especially designed to monitor the via defect rate in the manufacturing process continuously so the quality and yield loss due to via problems can be estimated. Some of them are placed in the kerf, but most of the structures shown below are characterization vehicles on dedicated wafers (designed by PDF solutions, 90 nm technology, see figure 2).

A via improvement strategy based on large test structures requires the ability to localize all types of via defects for root

cause identification. Four cases can be distinguished, where passive voltage contrast is ineffective:

- Contact chain on p- or n-substrate with hard open
 - Contact chain with soft opens (increased resistance) at one or more positions
 - Contact chain with higher resistance but all contacts are affected equally
 - Via chains on higher metallization with increased resistance
- In these cases AVC and SEI are the only suitable localization methods and complement each other.

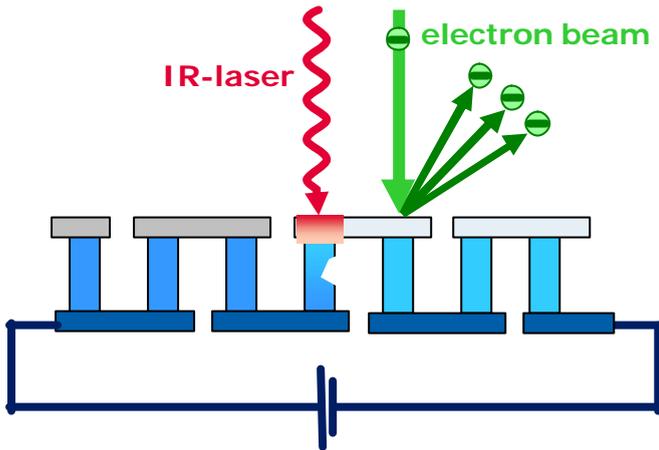


Figure 1: Localization of high resistive interconnections in a via chain.

SEI: The laser energy is converted to a heat gradient resulting in an SEI signal which is higher at a resistive via.

AVC: The electron beam generates secondary electrons that are reflected towards the detector in the grounded part of the chain, while being deflected by the applied potential in the biased part.

Results

Contact chain on p- or n-substrate with hard opens

Due to the small feature size contact chains are more often affected by defects than vias on higher metallization. A set of contact chains with numerous hard opens is shown in figure 2. All of the chains are connected by the same ground pad. When Seebeck Effect Imaging is executed, one microprobe is enough to contact all of the chains at the same time. The opposite electrode is represented by the substrate and the grounded chuck, respectively. In this setup it's not the actual Seebeck effect that's used for localization, also OBIRCH/TIVA could be chosen. The resulting contrast basically shows the area that is electrically connected to the microprobe and thus marks the point where the chain is interrupted. In figure 2, only the chain in the middle does not have a hard open. Additionally, areas with different intensity of the SEI signals can be recognized (see the arrows in figure 2) indicating high resistive contacts.

Two of the chains are enlarged in figures 3 and 4. In figure 3 a contact chain on substrate with two opens is shown where

three areas with different contrast can be differentiated with both methods. The position of the open contact is marked in the SEI images by the alternating contrast. In figure 4 only one open is detected, a small step in the border line can be seen at the open position (arrow).

As already described above, active biasing of the contact chain is needed for voltage contrast imaging to compensate leakage currents into the substrate. In figures 3 and 4 the AVC image is shown above the SEI image. It corresponds well to the SEI image and allows the localization of the same open contact. AVC is able to localize the first open contact on the side that has been electrically connected. A second open contact can be made visible by contacting the other end of the structure. More opens in between can only be localized under certain conditions: A voltage contrast difference is reached if the areas between two opens are significantly different in size. In this case these isolated areas vary in their sheet resistance and thus in their discharge behavior. In figure 5 we found two opens at the positions marked with the arrows, furthermore another open contact was seen at the far left end of the chain (position outside of the image). The area on the right side is bright because it's actively connected to ground; the left area is grey because it is positioned between two opens and isolated from the pads; the area in the lower middle is also isolated by opens but is the darkest because it has the highest sheet resistance due to its small size and is charged the most by the electron beam.

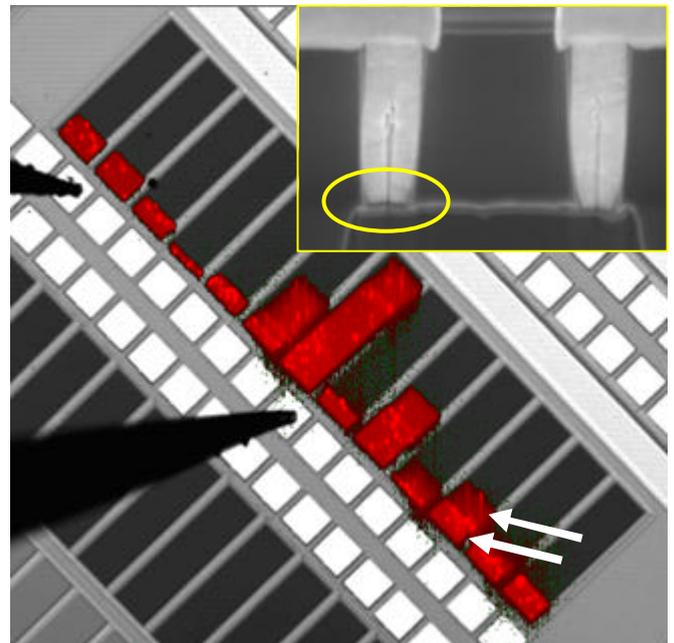


Figure 2: Overview of a set of contact chains that was used for this study (SEI overlay image). All chains are contacted by a common ground pad and show the position of several opens at the break off point of the red SEI signal areas. Note also the different shades of red in some of the chains indicating a soft open (arrows).

In the inset a typical defect is shown: The left contact is not completely filled.

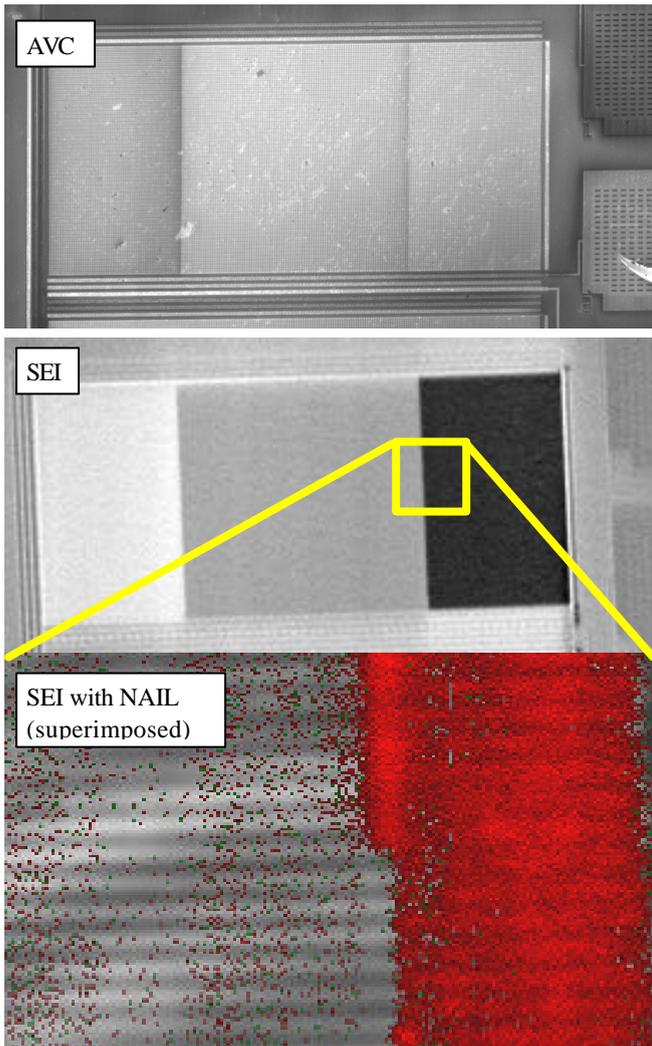


Figure 3: AVC and SEI image of a contact chain on substrate (two hard opens) with Si-NAIL. The chain (90nm technology) was connected at both sides so three regions with different contrast were visible. The area in the middle between the two opens is not directly connected to the pads. In the lower image the superimposed SEI image with high magnification with a NAIL is displayed (backside mode).

Compared with AVC, SEI has the disadvantage of lower lateral resolution. This drawback can be reduced by immersion lenses. In figure 3 SEI was performed in backside mode to allow the usage of a Si-NAIL. As can be seen in the lower image, at least the horizontal lines consisting of the contact bridges can be resolved in 90 nm technology (compare fig. 5 for SEM resolution).

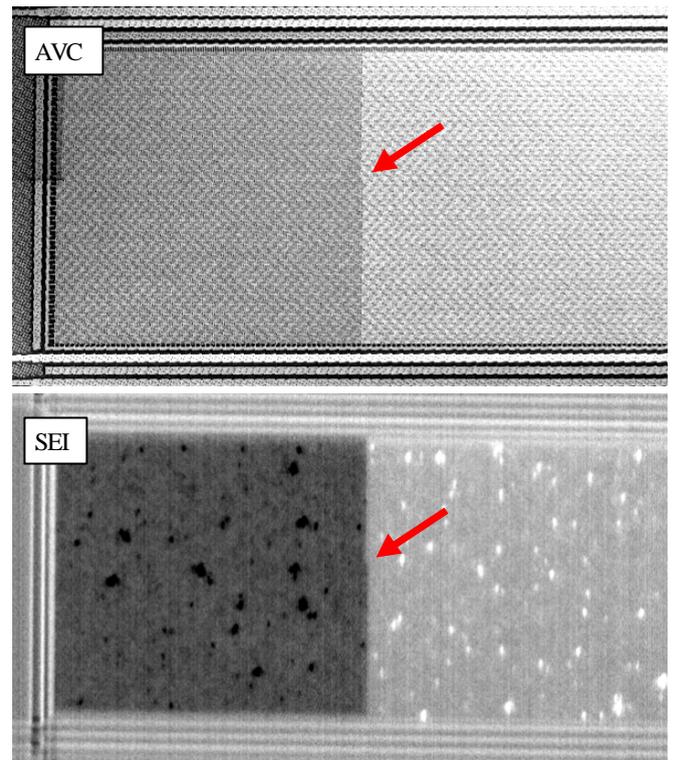


Figure 4: AVC/SEI comparison on contact chain on substrate with both soft and hard opens.

Upper image: Active Voltage Contrast image, lower image: Corresponding Seebeck Effect image. The structure is contacted with two probe tips. AVC clearly shows the position of the open, whereas SEI additionally marks numerous contacts with increased resistance (bright and dark spots), thus allowing a two-dimensional resistance mapping.

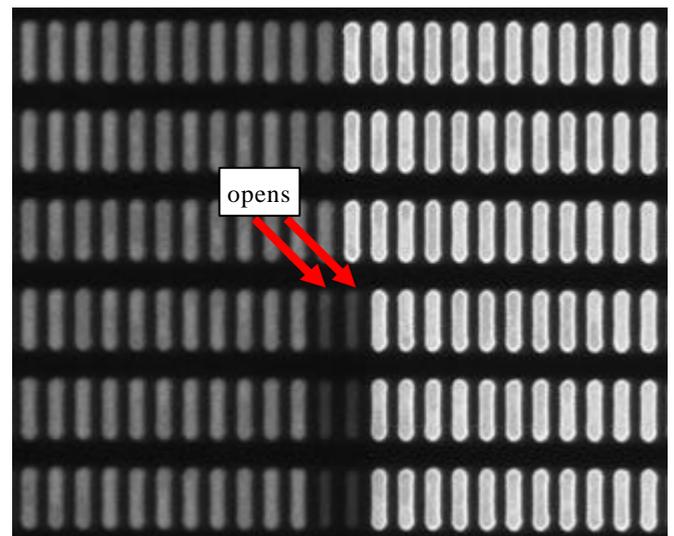


Figure 5: AVC on contact chain with different shades of contrast. Contrast depends on the area between the opens: The chain is darker between the two marked opens because the area is much smaller than the rest of the chain on the left

side. The small area leads to a higher sheet resistance to ground and stronger charging by the electron beam.

Contact chain with soft opens (increased resistance) at one or more positions

If the contact chain is not fully open but just a slightly higher resistance is measured, we are able to retrieve a similar voltage contrast as with hard opens. A little tuning of the voltage is needed to reach a stable contrast condition. The SEI image looks quite different, as no strong contrast is obtained. In figure 1 there are numerous „soft opens” found in addition to the hard open. Additional dark and bright spots show up pointing to contacts with slightly different resistance. The structure is contacted by two microprobes, so the soft opens are visible on both sides of the hard open. SEI provides a resistance mapping image that shows the lateral distribution of resistive contacts over the test structure and also correlates the resistance magnitude with signal intensity (small spots in figure 4).

In comparison, AVC will at least show the position of the contact with the highest resistance. Other resistive contacts can sometimes be localized by slowly increasing the applied voltage, so the dark/bright frontier jumps to another position. A detailed qualitative overview of the resistance distribution can only be done with SEI, which has the higher electrical resolution in this application.

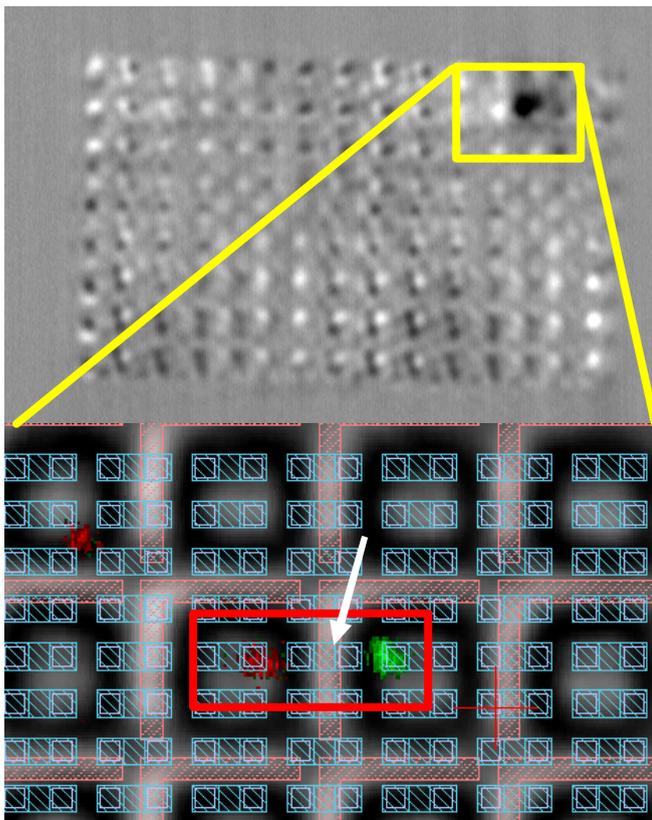


Figure 6: Via chain between metal 1 and metal 2 with a resistance value 1% above spec.

Exact localization with SEI down to an area of two interconnections using a NAIL is possible (130nm

technology). Overlay with layout is shown in the lower image.

Contact chain with higher resistance but all contacts affected equally

When all interconnections are affected in the same way, the resistance of the chain may be similar to a chain with one open interconnection only. This can't be decided by the electrical data. The localization with SEI or AVC in this case does not show any contrast across the chain. A continuous change from bright to dark between the two sides of the structure will be observed with AVC, and a SEI image will be uniform. This is also valuable information as it excludes e.g. a defect density problem and points to a process issue.

Via chains on higher metallization (without substrate contact) with increased resistance

If the electrical path is not completely open, passive voltage contrast will not give any results. This issue can be treated by both AVC and SEI. A satisfying contrast can be reached in AVC by applying a bias that compensates the small residual current flow. With SEI we can localize the same defect even if the chain is masked by upper metal layers.

The interesting question is the reachable sensitivity. In figure 6 a chain of interconnections between metal 1 and 2 is shown. The chain consists of 800 vias and is interconnected with three identical chains in a bridge circuit allowing a four point measurement. The chain exhibited a resistance merely 1% higher than that of its neighbors which translates to a resistance increase of a factor of 15 for one via, assumed that only a single via is affected. This case represents the lowest resistance limit we have to deal with in practice, as most via chains are much larger and the lowest detectable resistance increase of a single via is accordingly much higher. Moreover the electrical test structure parameters are usually only measured with two probes and with lower electrical sensitivity than in this example.

While we were not able to do successful localization with AVC, Seebeck Effect Imaging showed a strong signal after short integration time marking the suspicious area. With the use of a NAIL and layout overlay (fig. 6), it was possible to exactly localize the defect down to an area of two interconnections. The analysis was performed in backside mode through the substrate and poly layer.

Conclusions

Active Voltage Contrast allows localization of resistive interconnections under conditions that have previously prevented successful analysis, especially contacts on substrate or chains with slightly increased resistance. Seebeck Effect Imaging provides additional lateral resistance mapping in case of soft opens and makes differences between the interconnections visible with very high sensitivity.

Drawing on the example of test structures used for via quality monitoring, we showed that the two physical approaches yield

different information and complement each other. AVC has advantages in lateral resolution and speed as it allows localization and direct cross sectioning in one step. While SEI often overlaps with AVC, it makes resistance mapping of a large area possible and is the method of choice for marginal resistance increases with high sensitivity.

Only the combination of AVC and SEI delivers the complete view on resistive interconnection issues and covers the full resistance range.

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References

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